# Module-1

- **Definition: Smart materials**, also known as **responsive materials**, are intentionally designed substances that exhibit controllable changes in their properties upon exposure to external stimuli such as stress, moisture, electric or magnetic fields, light, temp., pH, etc.

- **Definition: Composites** are a mixture of 2 or more chemically different materials combined macroscopically to form a useful material.

- The differences between an alloy & a composite are as follows:

| Alloy | Composite |
|---|---|
| It's a mixture of 2 or more materials in the micro scale. | It's a mixture of 2 or more materials in the macro scale. |
| These are homogeneous mixtures. | These are heterogeneous mixtures. |
| These are isotropic in nature. | These are anisotropic in nature. |
| Ex: Brass, Bronze, Steel, etc. | Ex: Wood, Granite, Concrete, etc. |

- There are 2 types of composites:
  - Natural composites.
    - Living (e.g. Wood, Bones, etc)
    - Non-Living (e.g. Granite, etc)
  - Artificial composites (e.g. Concrete, CERMETS, etc).

- There are 2 phases or components of composite:
  - Matrix phase.
  - Reinforcement phase.

- Matrix phase is relatively lightweight but weaker compared to the reinforcement phase.

- The matrix phase generally serves as the **binding** constituent. The reinforcement phase generally serves as the **load bearing** constituent.

- Matrix materials are broadly classified based on their operating temperature range:
  - Polymer Matrix (less than 260°C).
  - Metal Matrix (260-750°C).
  - Glass Matrix (750-1100°C).
  - Ceramic Matrix (1150-1400°C).
  - Carbon Matrix (above 1400°C).

- Fibres, especially E-glass fibres, are commonly & widely used as reinforcements.

- **Definition: Natural fibres**, also known as **bio-fibres**, are those fibres which are derived from plants, animals, or minerals. They offer eco-friendly alternatives to synthetic fibres. Ex: flax, hemp, jute, etc.

- Natural fibres are commonly used in the textile & packaging industry.

- **Definition: Interface** refers to the boundary between the reinforcement phase & the matrix phase.

- There are 4 types of interfacial bonding:
    - **Mechanical bonding** occurs through the interlocking of interfaces, forming bonds that are typically effective when the force is parallel to the interface.

    - **Electrostatic bonding** occurs when opposite charges are present on the surfaces, resulting in a short range bonding interaction.

    - **Chemical bonding** occurs through the interaction of chemical groups at the interfaces, leading to interlocking between the reinforcement & the matrix.

    - **Reaction bonding** occurs when the molecules of the reinforcement & matrix materials undergo diffusion at the interface under the application of heat.

- The strength of the composite depends on various factors including:
    - Properties of reinforcement.
    - Volume fraction of reinforcement.
    - Inter-particle spacing of the reinforcement.

- Composites are used for making automotive parts such as fuel tanks, brake pads, hoods, etc. These are also used for making tennis rackets & other sports equipment.

- Composite materials exhibit better properties than its constituent materials.

- Advantages of using composite:
    - Increased strength.
    - Reduced weight.
    - Corrosion resistance.
    - Wear resistance.
    - Enhanced vibrational damping.

- Disadvantages of using composite:
    - Non-homogeneity.
    - Anisotropic.
    - High cost.
    - Non-biodegradability.
    - Complexity in manufacturing process.

- **Definition: Laminated composite** consists of layers of the same or different materials optimally bonded together.

  Examples of laminated composites are bi-metallic strips, safety glass, plywood, etc.

- Bi-metallic strips are made of 2 different metals with different coefficients of expansion.

- Safety glass is a type of glass made by sandwiching a layer of Poly-Vinyl Butyral between 2 layers of glass. It provides protection & enhances safety.

- **Definition: Cladding** is a process of coating 1 metal over another in order to combine the best properties of both metals.

- Fibres have a **high** length to diameter ratio. Whiskers have a **low** length to diameter ratio.

- Composites based on whiskers exhibit **stronger** mechanical properties compared to those based on fibres.

- **Definition:** In **random orientation composites**, the particles are oriented in random directions.

- **Definition:** In **preferred orientation composites**, the particles are oriented in a specific direction.

- All materials have better mechanical & thermal properties in the micro scale than in the macro scale.

- **Definition:** Fibre composites made of several layers, all oriented in the same direction, are called **single layer composites**.

- **Definition:** Fibre composites made of several layers, all oriented in different directions, are called **multilayer composites**.

- Glass fibres are generally of 2 types:
  - E-glass (Electrical glass) fibres.
  - S-glass (Strength glass) fibres.

- **Definition: Kevlar** is a type of aramid (aromatic polyamide) which is specifically used for the production of bulletproof jackets & military tanks.

- Ceramic fibres are always used in high temperature applications where their exceptional heat resistance is essential.

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# Module-2

- **Definition: Metal Matrix Composite (MMC)** is defined as the type of composite which uses metal or alloy as its matrix material with embedded reinforcements.

- Limitations of using metal as matrix material:
    - High temperature processing.
    - Heavy in weight.
    - Susceptible to corrosion.

- Metals like Aluminium & Titanium, & alloys like Nickel-Cobalt (Ni-Co) alloy are commonly used as matrix material in MMC, in order to overcome the above limitations.

- Ceramic particles or ceramic fibres are commonly used as reinforcements in MMC.

- Metal fibres are not used as reinforcements in MMC because of interfacial reactions that would occur between 2 incompatible metals.

- MMCs show higher fatigue strength & creep resistance, compared to the conventional alloys & metals.

- Methods of producing MMC:
    - Liquid state processing technique:
        - Melt stirring.
        - Gas pressure infiltration.
        - Squeeze casting or Pressure infiltration.

    - Solid state processing technique:
        - Diffusion bonding.
        - Deformation bonding (e.g. Roll bonding).
        - Powder processing.

- **Definition: Melt stirring** is a technique in which the metal or alloy is melted & the reinforcement particles are added while stirring the melt in order to ensure proper dispersion.

- **Definition: Infiltration** is defined as the process in which a material, often a liquid or a gas, diffuses into another material, usually a porous solid, to fill its pores, voids, or interstitial spaces through the action of capillary forces.

- **Definition: Gas pressure infiltration** is a technique that involves the use of a gas in order to facilitate the infiltration of the liquid metal or melt into the reinforcement.

- Gas pressure infiltration process has **longer** response times, compared to other processes.

- **Definition**: **Squeeze casting** is a technique that involves the application of pressure directly on to the melt in order to facilitate the controlled infiltration of the liquid metal or melt into the reinforcement.

- In squeeze casting, the applied pressure is maintained until the solidification of the molten metal is complete.

- Squeeze casting method has a **short** processing time.

- **Definition**: **Diffusion bonding** is a technique that involves the inter-diffusion of atoms between the metallic surfaces in contact at high temperature at the interface, resulting in the bonding of similar or dissimilar metals or alloys.

- **Definition**: **Deformation bonding** is a technique that involves the co-deformation of 2 ductile materials, resulting in 1 phase elongating & taking on a fibre-like form within the other phase.

- **Definition**: **Roll bonding** is a specific type of deformation bonding technique used for producing laminated composites by layering different materials together & passing them through a roller altogether, resulting in a sheet laminated MMC.

- **Definition**: **Powder processing** is a technique where a homogeneous mixture of matrix & reinforcement powders are either cold pressed & sintered or hot pressed directly in a die, in order to produce particle, particulate, fibre, or whisker reinforced MMC.

- **Definition**: **Pressing** is a manufacturing operation where pressure is applied to a homogeneous mixture of matrix & reinforcement powders placed in a die between 2 rigid punches.

- There are 2 types of pressing operation:
    - **Uniaxial pressing** involves placing the composite material in a die & applying pressure along a single direction. The resulting component may have anisotropic properties due to the directional pressure application.

    - **Isostatic pressing** involves placing the composite material in a die & applying uniform pressure from all directions. It results in components with more uniform density & reduced porosity.

- Isostatic pressing is a **slower** process compared to Uniaxial pressing.

- **Definition**: **Wettability** refers to the extent upto which a liquid can spread over a solid surface.

- There are 3 factors that affect wettability:
    - Surface type.
    - Surface topography.

- Contact area.

- Ceramic reinforcements have **poor** wettability, due to which, it presents challenges in proper infiltration of ceramic reinforcements with liquid melt (molten metal).

  This problem is resolved by using the squeeze casting process.

- **Definition: Deposition** is defined as the process of depositing a thin film or layer of material onto a substrate.

- Deposition process is of 2 types:
  - **Physical Vapour Deposition (PVD)** is defined as the process of depositing a thin layer of material onto a substrate by physical means such as impact or evaporation.

  - **Chemical Vapour Deposition (CVD)** is defined as the process of depositing a thin layer of material onto a substrate by chemical means such as chemical reactions.

- The rate of evaporation depends on the vapour pressure of the metal.

- **Definition: Reactive evaporation** is the process where reactions occur during the evaporation.

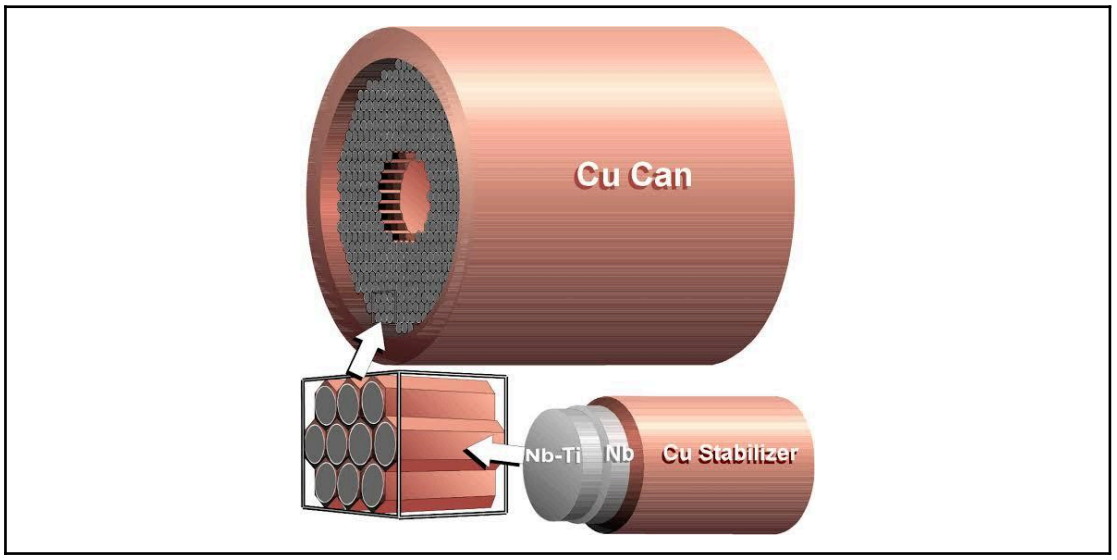
- Electron beam evaporation is a PVD process that results in higher film quality.

- The main drawback of the electron beam evaporation process is that it can damage the substrate with its X-rays & ions.

- The differences between PVD & CVD processes are as follows:

| PVD | CVD |
|---|---|
| It involves the deposition of material through physical means. | It involves the deposition of material through chemical means. |
| Here, the material to be deposited is in a solid state. | Here, the material to be deposited is in a gaseous state. |
| It's carried out at relatively low temperatures. | It's carried out at relatively high temperatures. |
| It produces films with good surface finish. | It produces films with good adhesion. |
| PVD coatings tend to be harder than CVD coatings. | CVD coatings tend to be thicker than PVD coatings. |

- **Definition: Multi-filament superconductor** consists of small superconducting filaments like Niobium-Titanium (Nb-Ti) alloy surrounded by a copper stabiliser.




- Copper is commonly used as the stabiliser because of its high heat capacity which helps in managing heat flux changes.

- Superconductors show **very high** resistivity in their non-conducting state.

- **Definition**: **In-Situ process** is defined as the process of creating composites by synthesising the reinforcing phase within the matrix material during composite fabrication.

- In-Situ means "situated in the original, natural, or existing place or position".

- Advantages of In-Situ process:
    - Improved mechanical properties.
    - Reduced manufacturing cost & time.
    - Simpler processing.
    - Increased design flexibility.

- **Definition**: **Spray deposition** or **spray forming** is a process of depositing a molten or semi-molten material onto a substrate by atomizing it into a fine mist with a high-velocity gas stream & then spraying it onto the substrate.

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## Module-3

- **Definition**: **Ceramic Matrix Composite (CMC)** is defined as the type of composite which uses ceramics as its matrix material with embedded reinforcements.

- CMC exhibits improved fracture toughness & higher loading capacity compared to MMC.

- Examples of CMC include:
    - Silicon carbide fibre with glass ceramics.

    - Silicon carbide whisker with alumina.

- Glass ceramics are of 2 types:
    - Oxide (e.g. silicate, borate, phosphate, & germinate).
    - Non-oxide (e.g. carbides & nitrides).

- **Definition: Technical ceramics**, also known as **engineering ceramics** or **industrial ceramics**, are materials characterised by their exceptional mechanical, electrical, thermal, & biochemical properties, meticulously engineered for specific engineering applications only.

- Technical ceramics are also of 2 types:
    - Oxide (e.g. silicate, borate, phosphate, & germinate).
    - Non-oxide (e.g. carbides & nitrides).

- The differences between technical & glass ceramics are as follows:

| Technical Ceramics | Glass Ceramics |
|---|---|
| These are crystalline. | These are amorphous. |
| These have high melting points & can withstand high temp. | These have low melting points & can be processed at relatively low temp. |
| These are hard & strong. | These are brittle. |
| Used in cutting tools, wear-resistant parts, & high-temp. applications. | Used in cookware, tableware, & optical components. |

- **Definition: Sintering** is a manufacturing process which involves heating a compacted material (usually in the form of a powder) to a temperature below its melting point, where the particles fuse together due to atomic diffusion at their contact points.

- Sintering of oxide ceramics typically requires a significant amount of time & high temperature, but applying pressure can help reduce the sintering time.

- Sintering is commonly carried out in tunnel kilns, & such kilns are generally divided into 3 zones:
    - Preheat zone (removes organic & oily materials).
    - Sintering zone (diffuses the ceramic particles together).
    - Cooling zone (cools the sintered part).

- Sintering is performed at relatively **higher** temperatures compared to reaction bonding.

- **Definition: Slip casting**, also known as **slip moulding** or **slurry moulding**, is a traditional ceramic manufacturing process which involves the formation of ceramic objects by pouring a slurry of ceramic powder called "slip" into a porous mould,

where the liquid component is absorbed by the mould, causing the ceramic particles to be drawn towards the mould walls.

- Slip casting is especially suitable for creating intricate & detailed ceramic pieces, as the fine particles in the slip can capture fine details of the mould.

- In the case of reaction bonded CMCs, the addition of the fibres or reinforcements to the molten ceramics enhances their high temperature properties. This process is generally carried out for glass matrix composites only.

- **Definition: Slurry infiltration** is defined as the process of infiltrating a fibrous reinforcement preform with a slurry containing particles of the ceramic matrix material.

  The slurry is driven into the preform by capillary action. After the infiltration is complete, the slurry is dried & then sintered to form a solid CMC.

- **Definition: Reactive Melt Infiltration (RMI)** is defined as the process of infiltrating a carbon preform with molten silicon, resulting in the formation of Silicon Carbide (SiC) matrix composites due to the reaction occurring between carbon & molten silicon.

- **Definition: Chemical Vapour Infiltration (CVI)** is defined as the process of infiltrating a heated reinforcement material with specific gases inside a reactor, where the gases react & form a ceramic deposit on its surface.

- The main disadvantage of CVI is that it causes high porosity within the material.

- **Definition: Sol-gel process** is defined as the process of fabricating CMCs from a colloidal solution (sol) that transforms into a gelatinous network (gel) through controlled chemical reactions, which is then sintered & crystallised into solid form.

- Advantages of sol-gel process:
  - Minimal reinforcement damage.
  - Lower equipment cost.
  - Ability to fabricate large & complex parts.

- Disadvantages of sol-gel process:
  - Lower yield & mechanical properties.
  - There is a possibility of cracking during the drying process.
  - The cost of the solution itself can be quite high.

- **Definition: Lanxide process**, also known as **pressureless metal infiltration**, is a way of producing CMCs by a process of partial reaction of MMCs in an oxidising environment, leading to the oxidation of metal matrix.

  Ex: Nicalon (SiC fibres), Alumina matrix composite, etc.

- **Definition: Carbon-Carbon composite**, often abbreviated as **C/C composite**, is a type of advanced composite material made primarily from carbon fibres & carbon matrix, & are known for retaining their high strength even at elevated temperatures due to their very large heat capacity.

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## Module-4

- **Definition: Polymer Matrix Composite (PMC)** is defined as the type of composite which uses polymer as its matrix material with embedded reinforcements.

- Types of polymer:
  - Thermosetting polymer.
  - Thermoplastic polymer.

- The differences between thermosetting & thermoplastic polymers are as follows:

| Thermosetting Polymer | Thermoplastic Polymer |
|---|---|
| These can't be melted & reshaped after having undergone the curing process. | These can be melted & reshaped even after having undergone the curing process. |
| These have cross-linked polymer chains, because of which they decompose instead of melting, when heated. | These have linear or branched polymer chains, because of which they melt easily when heated. |
| Ex: Epoxy resin, polyurethane, etc. | Ex: PVC (Poly-Vinyl Chloride), etc. |

- PMCs are manufactured by methods such as:
  - Vacuum & Pressure bag moulding.
  - Hand layup.

- **Definition: Fibre Reinforced Polymer (FRP)** composites are materials made up of a thermosetting polymer matrix reinforced with fibres.

- **Definition: Injection moulding** is a process which involves injecting a molten material mixed with a binder into a mould cavity under high pressure, allowing it to solidify & take the shape of the mould.

- **Definition: Autoclave** is defined as a sealed cylindrical chamber used for carrying out industrial processes under high temperature & pressure in an inert atmosphere.

- **Definition: Autoclave moulding** is defined as the process of manufacturing PMC, in which a mould filled with resin-impregnated fibre reinforcements are sealed in a vacuum bag & then cured under heat & pressure inside an autoclave.

- Autoclave moulding process is also known as the closed moulding process or vacuum bag moulding process.

- The main advantage of autoclave moulding is that it produces void-free products.

- The main disadvantages of autoclave moulding is that it's an expensive & time consuming process.

- **Definition: Resin Transfer Moulding (RTM)** is defined as the process of manufacturing PMC, in which a closed mould filled with reinforcement fibre preform is vacuum pulled & then injected or pressure infiltrated with resin & allowed to cure & solidify.

- **Definition: Pultrusion** is defined as a continuous manufacturing process which is used for producing consistent composite profiles by pulling the reinforcing fibres impregnated with thermosetting resin through a heated steel die.

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## Module-5

- **Definition: Sandwich structures** are composite materials consisting of 2 outer layers (face sheets) enclosing a lightweight & low-density core material.

- Sandwich structures offer high strength & high stiffness-to-weight ratio.

- **Definition: Foam core structures** are those structures which use lightweight foams, such as polyurethane or polystyrene, as the core material.

- The foams provide thermal insulation, damping properties, & reduce weight while maintaining structural integrity.

- **Definition: Honeycomb structures** are those structures which utilise hexagonal cells made up of materials like aluminium, nomex, or fibreglass as the core.

- Honeycomb structure provides high strength-to-weight ratio & distributes the load efficiently, making them suitable for aerospace applications.